THE HORIZONTAL MOVEMENT OF GEANTICLINES AND THE FRACTURES NEAR THEIR SURFACE

H. A. BROUWER
Delft, Holland

Most islands of the arcs which lie to the east and the southeast of the Asiatic continent show proof of an uplift of the land relatively to the sea-level, which is amply demonstrated in tropical regions by the presence of upheaved fringing reefs. In the East Indian Archipelago there exists a striking difference between the western and the eastern parts as regards the rising islands and the submarine topography. If the sea-level were to be lowered 200 m., Sumatra, Java, and Borneo would form one mass of land with the peninsula of Cambodia and Siam, just as Australia would form a single mass with the Aru Islands through the vast tract now occupied by the shallow Arafura Sea and the Bay of Carpentaria to New Guinea and the islands Misool, Waigeu, Batanta, and Salawati to the west of New Guinea.

Between these two near-land-masses lies an area in which deep sea basins alternate with upheaved islands. From a geological point of view Verbeek[1] first drew attention to this remarkable fact, of which a more satisfactory discussion has been made possible because of the new deep-sea chart of the Siboga Expedition.[2] In Verbeek's opinion the elevation of the islands surrounding the Banda Sea is the result of folding at greater depth. The active forces first began compressing near the surface, and as the geosynclines were formed they became active at greater depths. Later Molengraaff[3] expressed similar ideas, and for the southeastern por-

[1] R. D. M. Verbeek, "Rapport sur les Moluques," édition française du *Jaarb. v. h. Mÿnwezen in Ned. O. Indië*, Vol. XXXVII (1908), pp. 833, 834.

[2] G. A. F. Tydeman, "Hydrographic Results of the Siboga Expedition," Chart 1, in M. Weber, *Siboga-Expeditie*, Part III, Leyden, 1903.

[3] G. A. F. Molengraaff, "Folded Mountain Chains, Overthrust Sheets and Block-Faulted Mountains in the East Indian Archipelago," *Compte rendu du XIIe congrès géologique international*, Toronto, 1913, p. 699.

tion of the Malay Archipelago he distinguished two types of mountain-building: (1) the overthrust type of Miocene age, culminating in overthrusts of great magnitude, which was the expression of a very powerful, but not deep-seated compression, and (2) the block-faulted type of Plio-Pleistocene age, consisting of ranges of elevated islands alternating with deep sea basins, these being the expression of a deeper-seated, but perhaps less energetic compression.

It is only the vertical movements of the rows of islands that have been considered by these authors. In some recent publications[1] I have pointed out that:

1. The youngest crustal movements in this region are a younger phase in the same process as the older and an exact continuation of the mid-Tertiary crustal movements. Of the mid-Tertiary phase we know only the folds and overthrusts which represent action at greater depth; of the youngest phase only the fractured and faulted crust which represents action near the surface; but the two phenomena are mutually complementary and the rows of uplifted islands indicate the spots where the folding process continues at the greater depths with the same tendency to form overthrusts.

2. From the outline of the rows of islands we may conclude that they have a large movement in a *horizontal* as well as in a vertical direction.

The horizontal movements of the curving rows of islands are expressed by several of their characters.

1. The striking fact that the Tenimber Islands and the Kei Islands have an outlying position in the row and both are situated opposite a depression in the Sahul bank which constitutes the Australian continental shelf. Opposite these depressions the geanticline met with less resistance.

[1] H. A. Brouwer, "On the Crustal Movements in the Region of the Curving Rows of Islands in the Eastern Part of the East Indian Archipelago," *Proceed. Kon. Akad. v. Wetensch. Amsterdam*, Vol. XXII, pp. 772–82; "On Reef Caps," *ibid.*, Vol. XXI, pp. 816–26; "Fractures and Faults near the Surface of Moving Geanticlines," *ibid.*, Vol. XXIII, pp. 570–76; "Über Gebirgsbildung und Vulkanismus in den Molukken," *Geol. Rundschau*, 1917, p. 197; "Über die horizontale Bewegung der Inselreihen in den Molukken," *Nachr. d. Gesellsch. der Wiss. zu Göttingen*, 1920.

2. The coincidence of asymmetrical reef caps with marked outward bends of the row of islands, instances of which are found in the island Rotti to the southwest of Timor and in the island Jamdena of the Tenimber group.

3. The faults and fractures near the surface demonstrate differences in rate of horizontal movement between adjacent parts of the moving geanticlines.

In the following pages the above-described faults and fractures will be dealt with in connection with the vertical and horizontal movements of the geanticlines near the surface of which they occur. Because the geanticlines have risen from the sea and were in consequence exposed to eroding influences during a much shorter time than those of the continental mountain ranges, the outer form is not in the main controlled by erosion, but by the crustal movements themselves, and the latest phase of mountain-building manifests itself clearly in the shape of the geanticlines near the surface.

CRUSTAL MOVEMENTS AND MORPHOLOGICAL STRUCTURE

When crustal movements take place they generally cause the strata to break near the surface and to fold at greater depths. An extension of the geanticlinal axis is here obtained through gaping fractures, or by movements parallel to fault planes which must be inclined to the geanticlinal axis. Shortening of the geanticline is possible by faulting along fault planes which are not perpendicular to the geanticlinal axis. Similar relations prevail for a lengthening or a shortening of a section of the geanticlinal surface with a plane perpendicular to the geanticlinal axis.

In addition to the control by the direction and the rate of the movement, the position of the fault planes is determined by a great many other factors, e.g., by stratification and by the composition and distribution of the rocks near the surface. Leaving out of consideration those local areas within which the anticlinal axis shows an important pitch, the morphological aspect of the surface will be controlled chiefly by the more or less horizontal transverse faults, the gaping transverse fractures, the more or less longitudinal faults, and the gaping longitudinal fractures.

We are here considering those regions only of the geanticlinal surface where the faults, through their more or less equal position

and their more or less equal direction of movement, bring about considerable alterations in the broad outlines of the morphological structure. Zones of constant lithological characters will generally be separated near the surface by planes which are parallel to the geanticlinal axis. If these planes are more or less vertical, this will chiefly influence the distribution of the vertical longitudinal fractures and the longitudinal faults. If these planes are principally more or less horizontal, this will chiefly influence the distribution of the faults along horizontal planes, but they will be of little importance for the major morphological structure and will here be left out of consideration. Whether these planes are nearly vertical or nearly horizontal, the lithological character is of little importance for the distribution of the transverse faults and fractures which strongly influence the morphology at the surface of the geanticline. Thus we find that the outline at the surface is mainly controlled by the direction and the rate of the crustal movements in so far as the transverse fractures are concerned.

OLDER FOLDS CUT OFF BY THE PRESENT COAST LINE

The surface and the deeper parts of moving geanticlines will generally not move in the same direction and at the same rate, because:

1. The intensity and likewise the direction of the forces which cause the movement near the surface will generally be different from those which obtain at greater depth.
2. The transmission of directed forces will decrease from the surface to the zones of higher plasticity at greater depth.

If the forces which cause the movement are deep-seated, and the crust near the surface does not respond to the direct influence of the compressional or tensional stress, the displacements near the surface will be the result of the movement at greater depth. In forming a judgment on the genesis of fractures and folds this should be borne in mind.

A result of the difference between the movements at greater depth and those near the surface is that, if at greater depth the movement has a horizontal component, those points which were originally on the same vertical line will in a later stage of evolution of the geanticline form an irregular curve, the form of which will

depend upon the direction and the rates of movement at different depths. If a geanticline is elevated above the sea, the deeper-seated parts will gradually be uncovered by erosion and the surface of the geanticline will in time consist of rocks which were in the zone of flow during an earlier stage of the mountain-building process. As they are approaching the earth's surface, the rate and the direction of the motion may differ more and more from those at greater depths on the same vertical line.

That older folds terminate abruptly against the present coast lines is a phenomenon which is well known from Japan and from several islands of the East Indian Archipelago (Fig. 1). Particularly on Ceram this fact is very strikingly exemplified. In the

FIG. 1.—Older folds terminating abruptly against the present coast lines of the island of Ceram. (East Indian Archipelago.) Scale 1:3,000,000. ------ Approximate Tertiary strike.

greater part of the island the strike of the Tertiary mountain range is NW.-S.E., whereas the present coast line has for the middle part an east–west direction, so that the ridges of the high mountains terminate abruptly near Taluti Bay on the south coast and near Savai Bay on the north coast.

Similar facts have been explained by von Richthofen[1] as a result of tensional stress on a large scale, and he believed that the mountain arcs of eastern Asia, although bearing a great resemblance to the Alps and the Himalayas, have been formed by tensional, and not by compressional stress. Various authors have pointed out that this conception is not exact, and particularly because the fractures resulting from tensional stress are generally straight, whereas the ranges which lie to the eastward of the

[1] F. von Richthofen, "Geomorphologische Studien aus Ost-Asien, IV," *Sitzungsber. der Berlin. Akad. der Wiss.*, XL (1913).

Asiatic continent are arcs which present their convex sides to the oceanic areas. The tension hypothesis of Von Richthofen has been applied by some authors to the East Indian Archipelago, but the numerous fractures which without doubt exist near the surface can be explained in a simpler manner by the action of compressional stress.

It is not necessary to distinguish two periods of folding with different directions of the compressive forces, if we have regard for the fact that the older folds are cut off by the present coast lines. If the strike of the older folds is independent of the outlines of the present rows of islands, this may be in part a result of a change in the direction of the compressive forces; but it can be entirely a result of the fact that the folds which now appear at the earth's surface have been formed in a much earlier stage of evolution of the geanticline, and that during their elevation the horizontal component of the rate of movement was different for neighboring parts of the geanticline, while the transmission of the directed forces has increased and the intensity and the direction of the forces has changed, whereas at greater depths the plastic deformation has continued.

GROUPS OF SMALL ISLANDS WITH HIGH REEFS

In many rows of islands the breadth of each island is in direct proportion to the amount of elevation. In the Timor-Ceram range the long and broad island of Timor shows elevated reefs at the altitude of 1,300 m. in its central part, whereas in the short and much narrower island of Rotti elevated reefs are known at an altitude of but 470 m. This will generally be true wherever the vertical motion prevails. The increase in breadth results from the fact that the vertical component of the rate of movement has generally been in the same direction near the coast as it has near the axis of the geanticline. If the distance of the geanticlinal axis from the coast line be considerable, the vertical component of the movement need not be the same for longitudinal and for transverse coasts. The length of the island may still increase though the breadth decreases, or both may decrease and the island get shorter and narrower, while the top is still moving upward. However, if the geanticline shows

a normal evolution, high reefs will always be found on large islands.

If this is not the case, and if adjacent small islands show elevated reefs at high altitudes, this points to the existence of fractures. This case is illustrated by the islands of the Babber group (Fig. 2). Some fine specimens of terraced islands are found in this group. In Babber the uppermost elevated reefs are found at an altitude of 650 m.;[1] the small island of Dai with a steep coast has fifteen terraces, the highest at 620 m. above sea-level; the small island of Dawera has probably sixteen terraces; and Daweloor has fourteen entirely covered with reefs. On Dawera the highest point is at an altitude of 328 m., and on Daweloor of 280 m. On Wetan, which also consists entirely of upheaved reefs, there are six or seven terraces in the southern part with a maximum altitude of 320 m. Wetan is separated from Babber by a narrow and deep strait without reefs.[2] Kisser, a small island of the Sermata group shows the same characteristics, having a fine terraced appearance with the highest reefs at an altitude of 147 m., though in the neighborhood of its coasts the sea bottom falls off rapidly to great depths.

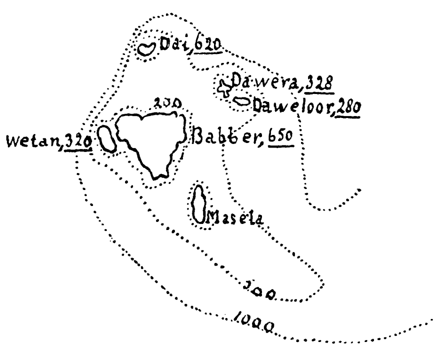

FIG. 2.—The islands of the Babber group. (Southeastern Malay Archipelago.) Scale 1:3,000,000. 320, etc., altitude of the uppermost elevated reefs in meters. 200, 500, 1,000, submarine contours in meters.

THE EVOLUTION OF PARALLEL ROWS OF ISLANDS AND LONGITUDINAL FRACTURES STUDIED IN THE PROFILE

If we consider the evolution of geanticlines in a direction parallel to the geanticlinal axis, we find long and high islands where they are highest, and small and low islands at the depressions of the

[1] F. A. H. Weckherlin de Marez Oyens, "De Geologie van het Eiland Babber," *Handel. v. h. XIVe Nat. en Geneesk. Congres* 1913, pp. 463–68.

[2] R. D. M. Verbeek, *op. cit.*, p. 458.

axis. In the present-day stage of mountain-building this fact is illustrated by the Timor-Ceram row of islands, where a well-marked culmination occurs in the central part of Timor and well-marked depressions are found to the east and to the west of it. Secondary culminations and depressions are also found.

Sometimes two more or less parallel ranges of islands have the same direction as the geanticlinal axis. An example in the East Indian Archipelago is supplied by the islands of the Tenimber group, where the row which includes the main island Jamdena is

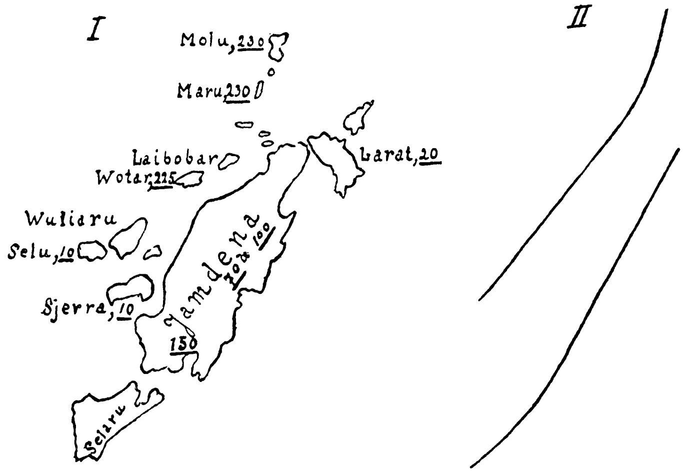

FIG. 3.—I, The islands of the Tenimber group. (Southeastern Malay Archipelago.) Scale 1:3,000,000. 225, etc., altitude of the uppermost elevated reefs in meters. II, The axes of the two secondary geanticlines (schematic representation).

accompanied by another row including the islands Selu, Wuliaru, Wotar, Laibobar, Maru, and Molu. The latter row differs from that of Jamdena in that it consists of smaller islands, although the elevated reefs are known at higher altitudes. On Wotar they are found at an altitude of 225 m., whereas on the main island Jamdena of the southern row the greatest height is at most 150 m. The reef cap, which covers Jamdena nearly continuously, is asymmetric, rising gradually from the northwestern coast in the direction of the main watershed of the island and thence descending rapidly toward the southeastern coast. I have explored portions of the coast of

the gently sloping northwestern part of this asymmetrical geanticline and found drowned river valleys which were observed far inland from the coast. Thus the upheaved island Jamdena is separated from the row of upheaved islands to the northwest by a zone which is covered by the sea, and in which during the youngest evolution of the geanticline positive movements have prevailed.

These facts can be explained in much the same way as has been done by Escher[1] for the group of islands southeast of Celebes which are known as the Tukang Besi Islands and which consist of four rows. Two of these rows consist of islands with elevated reefs which mark the anticlinal axes, whereas the two remaining show barrier reefs and atolls which mark the synclinal axes (Fig. 3).

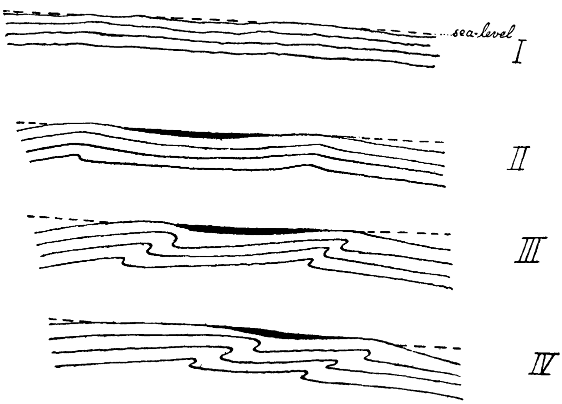

FIG. 4. One of the possible evolutions of two parallel rows of islands, of which different phases are represented in the southeastern Malay Archipelago (schematic representation). IV, Stage with elevated central basin.

We suppose that the geanticline at the Tenimber Islands is developing as two secondary geanticlines with an intermediate secondary geosyncline. The greater breadth of the islands in the southeastern secondary geanticline (although the reefs are not elevated to higher altitudes) may be the result of the prevalence of horizontal movements which caused the development of the asymmetrical reef cap (Fig. 4).

[1] B. G. Escher, "Atollen in den Nederlandsch Oost-Indischen Archipel: De Riffen in de Groep der Toekang Besi Eilanden," *Meded. Encyclop Bureau*, Afl. XXII (1920).

The further evolution of the geanticline can take place in different ways. If we suppose that in the next stage the plastic deformation of the northwestern secondary geanticline at greater depth causes chiefly a movement in a horizontal direction, the region of strongest upheaval will be displaced to the southeast. We may suppose that the rows of islands move in the direction of Australia, which for our considerations is the same as if Australia moved in the direction of the row of islands. Hobbs[1] has pointed out that mechanical difficulties disappear if the principal active forces involved in the folding of the Alps are considered as directed from the northwest toward the southeast. So far as our general conclusions are concerned, we may consider these movements as relative and not as absolute. The upper parts of the secondary geanticline do not move at the same rate and the higher parts of the folds were originally above the downward-moving secondary geosyncline. In a later stage of evolution these may be above the rising northwestern secondary geanticline and will be elevated above the sea.

Though differing in details, the geanticline of Timor may represent a later stage of geanticline evolution than the Tenimber Islands. In Pliocene time the geanticline near Timor was subjected to prolonged denudation and almost entirely disappeared below the sea. The crustal movements resulted in the development of two geanticlines and an intermediate, in part subdivided, geosyncline (cf. Molengraaff, *op. cit.*, p. 694), which became throughout fairly well filled by an accumulation of late Tertiary sediments deposited during a period of slow subsidence. Flexures and faults of considerable horizontal extent occur in the limbs of the geosyncline, which have caused the Pliocene strata within the basin to become bent abruptly upward near the edges. These longitudinal flexures and faults, which are essentially the same phenomenon, are the surface expression of an earlier, more plastic deformation at greater depth. Reefs and other littoral deposits spread over a great area, and after a certain period of evolution a great portion of Timor must have been covered by a sea full of

[1] W. H. Hobbs, "Mechanics of Formation of Arcuate Mountains," *Journal of Geology*, Vol. XXII (1914), p. 85.

coral islands and reefs, from which the islands emerged which are now the higher mountain groups of the present much enlarged island.

A similar stage of evolution is now to be observed in the same range of islands more to the east. The islands of the Sermata group clearly illustrate the movements of reefs in the period of development of the geanticline in which only its highest parts emerge from the sea as a group of smaller islands. The island of Luang has an altitude of 260 m. and, according to my observations, is built up entirely of Permian rocks. Together with two small islets at its southeastern extremity, it is fringed by a very broad reef, extending far to the east in the direction of Sermata and far to the west as well. Green islets far from the north coast, and barren, dry portions far from the south coast, mark the limits in northern and southern direction; beyond them the sea floor declines rapidly. Luang as well as the two small islets close to it rise up steeply from this broad reef, and no trace of elevated reefs was detected; the islands impress us as having originally formed one continuous whole and as having been separated by a positive movement, which may also account for the formation of the broad encircling reef.

In its eastern part the island of Moa consists of a low, very broad plateau of coral limestone, which rises scarcely more than 10–20 m. above the sea. From this plateau rises the steep Kerbau Mountain to an altitude of 400 m. Elevated reefs are lacking on the slopes of this mountain, and if the eastern part of Moa were a little lower, this region would present an aspect similar to that of Luang. The Island of Lakor, between Luang and Moa, consists of a low coral plateau, and Meaty Miarang forms the southern part of a large atolliform reef on the northern part of which lie the two low Ukenaö Islands. To the east of Luang and to the west of the eastern part of Moa the reefs are elevated to much greater altitudes and the group of the Sermata Islands shows a well-marked depression of the geanticlinal axis of the Timor-Ceram row. This part is much disturbed by transverse fractures and no sufficient data are available for judging whether the submersion observed on some islands is the consequence of the pitch of the geanticlinal axis only, or whether this region has passed, or will in the future

pass, through a stage with a secondary geosyncline between two secondary geanticlines.

After the Plio-Pleistocene reefs had been formed, a general elevation of the island of Timor took place. The elevation of the land has been somewhat greater at the edges of the secondary geosyncline than in the geosyncline itself, but the general movement resulted in the formation of a large anticline with the highest elevated reefs in the central part of the present island. In this latter stage of evolution the horizontal movements near the surface may have had a much smaller rate of movement than those at greater depth, while the central basin was gradually upheaved above the sea. The horizontal movement at greater depth may have prevailed in one of the secondary geanticlines only, but this is not a necessary condition. In our Figure 4 one of the possible modes of upheaval is represented.

DIFFERENT TYPES OF GEANTICLINAL MOVEMENT

The movement of a geanticline can be broadly described in the first place, in terms of the movements of the projections of the geanticlinal axis on the horizontal plane and on a vertical plane approximately parallel to the part of the geanticlinal axis under consideration. It is next of importance to take note of the movement of the section of the surface of the geanticline with a vertical plane at right angles to the geanticlinal axis. At the beginning of the movement we consider the geanticlinal axis to be a straight line; in a later stage this line will not be the geanticlinal axis, but for an approximate judgment this method is sufficient. The projections would undergo no changes in form if the geanticlinal axis was displaced parallel to itself. In general the vertical as well as the horizontal projection will develop a curved form. Some general types are given in Figure 5.

In Diagram I of Figure 5 the differences of plasticity and rate of movement between the surface and the deep-seated parts will have an influence on the development of longitudinal fractures only. The deformation of the sections perpendicular to the geanticlinal axis will be influenced by the place, the speed, and the duration of these fracture movements.

In Diagram II of the same figure the same considerations apply. The bending of a_2^1 will be much less than that in the figure, and the distinct traces of transverse fracture movements on the islands will disappear rapidly through erosion, although they may be perceptible near the transverse coasts.

In Diagram III of the figure more or less longitudinal fractures may develop, which in connection with the deformation of the

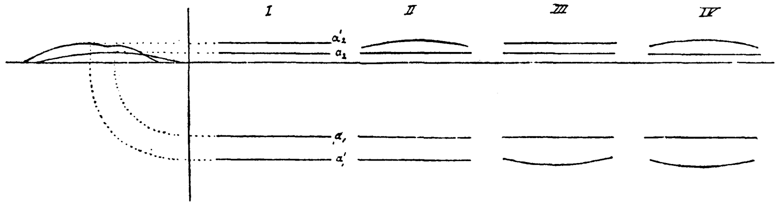

FIG. 5.—I, Displacement of the geanticlinal axis parallel to itself. II, III, and IV, Displacements in which the vertical or the horizontal projection, or both, have obtained a curved form.

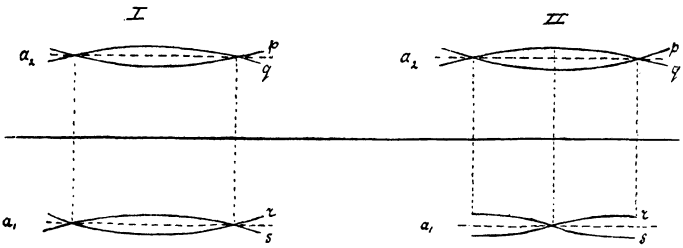

FIG. 6.—Deformations of the horizontal and vertical projections of the geanticlinal axis neglecting any displacements parallel to themselves.

sections perpendicular to the geanticlinal axis will be more or less important. Transverse fractures may be observable especially at the straits between the different islands of a row. Diagram IV is a combination of Diagrams II and III.

If in Diagram II, a_2^1 has one or more bending-points, which is equivalent to the development of transverse folds normal to the geanticlinal axis, then the place, rate, and duration of the transverse fracture movements near the surface may be strongly influenced by these folds. The same considerations are applicable to IIIa_1^1, and to IVa_2^1 or IVa_1^1, or to both of them.

If we consider Diagram IV, the more general type of deformation, supposing that the horizontal and the vertical projections of the geanticlinal axis have an equal number of bending-points, then two different types can be distinguished according as the bending-points of the horizontal and vertical projections alternate or do not (Fig. 6).

In this figure the combinations *p-r*, *q-s*, *q-r*, and *p-s* are different curves in space to which the originally rectilinear geanticlinal axis *a* has been distorted. The displacement of the geanticlinal axis parallel to itself and the distortion of the sections perpendicular to the geanticlinal axis are left out of consideration. The bending of *p* and *q* is much less than that which is shown in the figures. It would be more important if a strong compression had been acting in the direction of the geanticlinal axis from which would result a deformation to transverse folds normal to the geanticlinal axis. In this connection it is necessary to consider the geanticline over sufficiently long distances to obtain a judgment concerning the deformation of the vertical projection of the geanticlinal axis.

APPLICATION TO THE TRANSVERSE FRACTURES OF THE TIMOR-CERAM ROW OF ISLANDS

If considered over large distances it might seem that the geanticline, Sumba-Rotti-Timor-Sermata Islands, represents approximately Type I. The uppermost elevated reefs are found in Central Timor at an altitude of 1,300 m.; in West Timor, southeast of Kupang, they are at a height of 500 m., on Rotti at 470 m., and on Savu at 300 m. In East Timor the altitude is estimated at 600 m., on the islands farther to the east such reefs are known at altitudes of 140 m. on Letti and of 20 m. on Lakor, while on Luang no elevated reefs are found (cf. also Fig. 7). Thus the part, Sumba-Savu-Rotti-West Timor of the geanticline, would represent approximately I *p-r*, and the part, Central and East Timor–islands farther to the east, would represent I *q-s*.

If considered in detail the deformation is much more complicated. The deformation of the vertical projection is very slight and in many cases it is not exactly known. If the motion of the geanticlinal axis parallel to itself be neglected, this projection

nearly coincides with a, and the distinction between I a_2-r, I a_2-s and II a_2-r, II a_2-s disappears. Between Rotti and West Timor (Fig. 7) II p-r may be represented, but the deformation of the horizontal projection is the only important one.

The strait between Timor and Rotti coincides with a bending-point of the horizontal projection of the geanticlinal axis. In seeking an explanation for the existence of this strait, we might suggest the pitch of the geanticlinal axis on both sides of the strait, while at the place of the strait the axis could disappear below sea-level. But if considered in detail, this explanation alone is not applicable. On Rotti we find between the main island and the peninsula of Landu a narrow strait which only recently has been

FIG. 7.—I, Rotti, Timor, and the Sermata Islands. 470, etc., altitude of the uppermost reefs in meters. Straits and transverse dislocations are near the bending-points of II. II, Geanticlinal axis with bending-points between Timor and Rotti and between Timor and the Sermata Islands.

filled up by a mud bank still inundated at spring tide. At both sides of the narrow strait high walls of elevated coral limestone occur, and during an exploration of the island I found a small isolated rock composed of coral limestone which emerges from the mud in the middle of the strait. These facts point to the existence of transverse gaping fractures formed by a movement with a component normal to the fracture plane. We have already mentioned similar facts in connection with the groups of small islands having high reefs.

Another example of the same sort is found to the east of Timor (Fig. 7). Considering the large bendings only, a bending-point is located between East Timor and the Babber group; but if considered in detail bendings of smaller amount may also be observed. We note a bending of the geanticlinal axis between East Timor and

Letti of the Sermata group, and in the neighborhood of the bending-point we observe the northern, non-harmonic position of the small island Kisser which is covered by elevated reefs and surrounded by deep seas. There is here again the evidence that bending of the geanticline at greater depth is accompanied by transverse fractures near the surface. The fractures which occur farther to the east and their connection with the sharp bending in the 200 m. contour line of the Sahul shelf has already been discussed in earlier papers.[1]

Still another example is found between Ceram and Buru (Fig. 8). A very striking irregularity in this portion of the geanticline is the narrow Manipa Strait, nearly 5,000 m. deep between Ceram and Buru, here also near the bending-point of the horizontal projection of the geanticlinal axis. If this bending-point is not so clearly visible in the present topography, for the reason that the fracture movements are very strong, it may be inferred from the strike of the Tertiary mountain range. In West Buru and in the greater part of Ceram this strike is about NW.–SE., whereas in West Ceram and in the islands between Ceram and Buru it is E. NE., and NE. strikes also have been observed (cf. Fig. 1).[2] Thus the Tertiary mountain range displays a considerable bending from Ceram to Buru. As we have pointed out, the strike of the folds and the overthrusts of the Tertiary phase of crustal movement, and

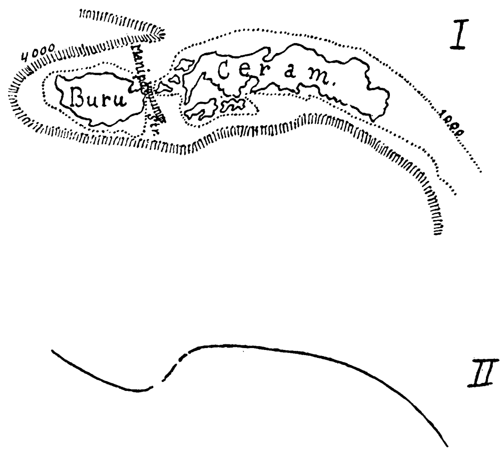

FIG. 8.—I, The deep Manipa Strait (+4800 m.) between Ceram and Buru. 1000, 4000, submarine contours. II, Geanticlinal axis with strong transverse dislocations near the bending-point.

[1] H. A. Brouwer, *loc. cit.*

[2] L. Rutten and W. Hotz, "De geologische Expeditie naar Ceram," *Tydschr. Kon. Ned. Aardr. Gen.*, Vol. XXXVI (1919), 9e Verslag.

the fractured and faulted crust near the surface of the youngest phase of the deformation are the result of different stages of the same process. As has been stated above, p and q will nearly coincide with a_2, and the bending of p and q is much less than is represented in the figures. In the case of the Strait of Manipa a compression may even have been acting in the direction of the geanticlinal axis so that the origin of the strait may in part be due to transverse folding. But no sufficient data are as yet available for an exact judgment on the problem of deformation in space.

We have seen that in the large bendings of the geanticlinal axis a distinction between Types I and II can be made, though if considered for bending at relatively small distances, these two types are very similar for the reason that p and q nearly coincide with a_2. In the Timor-Ceram row the following rule seems to be approximately applicable:

Considerable transverse fractures near the surface of the moving geanticline coincide with bending-points of the horizontal projection of the geanticlinal axis.

In most cases it is clearly observable that the fractures near the surface have been formed by a movement having an important component normal to the fracture plane, and that the fractures near the bending-points are the surface expression of *differences in rate of movement* of neighboring points in the horizontal projection of the geanticlinal axis.

RELATIVE AND ABSOLUTE HORIZONTAL MOVEMENT

If we neglect the displacement of the geanticlinal axis parallel to itself, as has been done, we find evidence only for the relative horizontal displacements of different points in the geanticlinal axis. The absolute horizontal movement may be considerable, but it cannot be inferred from the surface characters of the present geanticlines. If our interpretation of the evolution of the central basin of Timor is correct, important absolute horizontal movements must have taken place at greater depth, while the superficial parts moved at a slower rate. This conception agrees with the interpretation of the evolution of the Western Alps, as this has been

demonstrated by Argand.[1] Here likewise we see that in Mesozoic time geanticlines formed, separated by geosynclines, and that these have been moved in a horizontal direction. It may be that the southeastern Indian Archipelago will in the future arrive at the same stage as was long before reached in the Alps. As the horizontal movements proceed, the sea basins will narrow, and eventually the masses of the deeper parts of the present rows of islands will be pushed over the present Australian continent and the Sahul shelf which extends its borders. For a judgment, whether the active force tending to produce movement is directed to the southeast or to the northwest, as would follow from the conceptions of Hobbs[2] and Wegener,[3] no sufficient data are available.

[1] E. Argand, "Sur l'arc des Alpes occidencales," *Eclogae Geol. Helv.*, Vol. XIV (1916), p. 179.

[2] W. H. Hobbs, *op. cit.*, p. 91.

[3] A. Wegener, "Die Entstehung der Kontinente und Ozeane," *Die Wissenschaft*, 1920.